SUB-MARINE SOLUTION OF LIMESTONE IN RELATION TO THE MURRAY-AGASSIZ THEORY OF CORAL ATOLLS

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In 1880 Murray[1] advanced the idea that the solvent action of sea-water for limestone was a primary factor in the deepening and widening of the lagoons of coral atolls. This idea was afterwards adopted by Alexander Agassiz[2] who became its most active advocate. In 1914 Dole[3] made a chemical study of the water of the lagoon of the atoll of Tortugas, Florida, and decided that it contained no free carbon dioxide, and Tashiro[4] pursuing a different method decided that if free carbon dioxide be present in Tortugas sea-water its amount must be slight. In view of these facts Vaughan[5] stated that lagoons of atolls could not have been dissolved out by sea-water as such, but he gave no quantitative data to support this view. The validity of the Murray-Agassiz theory depends upon the *rate* of the solution of limestone in atoll lagoons. Elschner[6] states that the solubility of calcium carbonate in sea-water is extraordinarily low but he also gives no quantitative data. I have made an attempt to determine the rate of solution of calcium carbonate in Tortugas sea-water. Carefully weighed pieces of the shell of the mollusc *Cassis* having a specific gravity of 2.88 and areas ranging from 57.6 to 85 sq. cm. were treated as follows:

Shell No. 1 was placed for 367 days in a sealed, sterilized, glass carboy containing 45 liters of doubly filtered sea-water, which after being filtered was heated within the carboy to 72.5°C. for two hours. At the end of the year this sea-water still retained 71% of its alkalinity to phenolphthalein test. No bacteria or other visible growths developed within this carboy and the shell remained clean and without slime upon its surface. This shell weighed 13.285 grams in July, 1914 and at the end of the year it had lost 0.014 gram. Thus it would have taken 948 years to dissolve the shell, and a thickness of 0.00067 mm. was removed from its surface by one year's immersion.

Shell No. 2 was placed in another similar carboy, but the sea-water was neither filtered nor sterilized, and it developed bacteria, protozoa and algæ, and at the end of the year it was acid; its free acidity over and above neutrality by phenolphthalein test being equivalent to $\frac{n}{3000}$ H_2SO_4. The shell originally weighed 15.532 grams and it lost 0.173 gram after 360 days. Hence it would have taken 90 years to dissolve the shell, and a superficial thickness of 0.007 mm. was removed in one year.

Shell No. 3 was placed for 364 days in a 15 liter glass bottle which was enclosed in a wooden dark chamber to prevent the growth of plants. The water was mechanically changed by each rise and fall of the tide, flowing in and out of small glass tubes, thus preventing the formation of strong currents within the bottle. This bottle was placed in the marine moat surrounding Fort Jefferson, Tortugas. This moat-water supports an abundant animal life and contains more CO_2 than the open ocean, but remains always alkaline to phenolphthalein. At the beginning of the experiment the shell weighed 10.5435 grams, and at the end of the year it had lost 0.0115 gram. Thus it would have taken 917 years to dissolve the entire shell and a superficial thickness of 0.00069 mm. was removed in one year.

Shell No. 4 was placed for 364 days in a similar glass bottle which remained between tides off the western wharf of Loggerhead Key, Tortugas, thus being surrounded by open sea-water. Considerable silt was drawn in through the glass tubes, and the shell was found buried beneath about 8 mm. of limestone mud which was charged with H_2S. A number of tunicates, shrimps, molluscs and worms were living within the bottle at the end of the year, but the circulation had become interrupted by the growth, within the bottle, of a tunicate across the opening of one of the tubes. The shell originally weighed 15.22 grams and it had lost 0.047 gram, amounting to a superficial thickness of 0.0019 mm. in a year. Thus it would have required 324 years to dissolve the shell.

Taking the results of this last experiment as a maximum rate of solution of calcium carbonate by sea-water as such, it appears that 19,250,000 years would be required to dissolve out a layer of calcium carbonate to a depth of 20 fathoms, this being about the average depth of atoll lagoons; and as many if not all atoll lagoons have been formed since the beginning of Tertiary times it appears that they owe their development to agencies other than that of solution by sea-water, for even if the rate of solution of reef limestone is 100 times as rapid as that of the *Cassis* shell it would require 192,500 years to dissolve out an average lagoon.

Holothurians, Echini, boring algæ, certain sponges, worms, dead organisms, and probably most important rain water washing out from forested shores are agencies which dissolve limestone but their effects have not yet been quantitatively evaluated. Thus the lagoons of barrier reefs surrounding volcanic islands may have been formed in some appreciable measure by solution, but this cannot apply in the same degree to the lagoons of atolls where the land area is insignificant in

proportion to the area of the basin of the lagoon, and we know from the studies of Guppy, Wood-Jones, and Vaughan that many lagoons are filling up with sediment. In fact calcium carbonate is being precipitated from the sea-water of the Florida-West Indian region in the manner determined by Drew[7] and Kellerman and Smith;[8] the precipitate finally changing into oolite as observed by Vaughan.[9]

[1] Murray, J., *Edinburgh, Proc. R. Soc.*, **10**, 505 (1880).

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[3] Dole, R. B., The Carnegie Institution of Washington, Publication No. 182, *Papers from the Tortugas Laboratory*, **5**, 711 (1914).

[4] Tashiro, S., Year Book of the Carnegie Institution of Washington, No. 13, p. 220 (1915).

[5] Vaughan, T. Wayland, Publication No. 182, The Carnegie Institution of Washington, p. 62, (1914); also 1914; *Bull. Geol. Soc. Amer.*, **26**, 58 (1914).

[6] Elschner, C., *The Leeward Islands of the Hawaiian Group, Honolulu*, p. 48, (1915).

[7] Drew, C. H., Carnegie Institution of Washington, *Paper from Tortugas Laboratory*, **5**, 7-45 (1914).

[8] Kellerman, K. F., and Smith, N. R., *Washington, J. Acad. Sci.*, **4**, 400 (1914).

[9] Vaughan, T. Wayland, Carnegie Institution of Washington, Publication No. 182, p. 47-54 (1914).

THE ARCHEGONIUM AND SPOROPHYTE OF *TREUBIA INSIGNIS* GOEBEL

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Treubia insignis is a remarkable liverwort discovered by Goebel in Western Java. It is one of the largest and most striking species known and is of special interest as being in some respects the nearest to the typical leafy liverworts of any of the 'anacrogynous' Jungermanniales.

For some time after its discovery Treubia was known only from the original locality near Tjibodas on Mt. Gedeh in Western Java. It has since been discovered in several widely separated regions, e.g., New Zealand, Tasmania, Patagonia, Tahiti, and Samoa. In May 1913, I collected a single specimen on Mt. Banajao in Luzon, Philippine Islands.

The present paper is based upon material collected at the original station (Tjibodas), in 1906. The material comprised female and sterile plants with gemmae, but no male plants were found.

The archegonia are in groups, up to a dozen, protected by the characteristic dorsal scales which occur at the base of each leaf.

The development of the archegonium is much like that of other liverworts, but shows one striking difference—instead of the usual five or six rows of peripheral cells in the neck of the archegonium, there may be as